FORESTRY

FRDA REPORT 162

Effects of Time of Planting of Engelmann Spruce in the Lillooet Forest District, British Columbia

ISSN 0835 0752

DECEMBER 1990

ECONOMIC & REGIONAL DEVELOPMENT AGREEMENT

Canada

BC

91-06868/

Effects of Time of Planting of Engelmann Spruce in the Lillooet Forest District, British Columbia

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Canada

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Funding for this publication was provided by the Canada-British Columbia Forest Resource Development Agreement - a five year (1985-90) $300 million program cost-shared equally by the federal and provincial governments.

Canadian Cataloguing in Publication Data

Main entry under title:
Effects of time of planting of Engelmann spruce in the Lillooet Forest District, British Columbia

(FRDA report, ISSN 0835-0752 ; 162)

Issued under Canada-BC Forest Resource Development Agreement.
Co-published by B.C. Ministry of Forests.
"Canada/BC Economic & Regional Development Agreement."
Includes bibliographical references. p.
ISBN 0-7726-1317-6

1. Engelmann spruce – British Columbia – Squamish-Lillooet – Planting time. 2. Engelmann spruce – British Columbia – Squamish-Lillooet – Seedlings. 3. Forest site quality – British Columbia – Squamish-Lillooet. 4. Lillooet Forest District (B.C.) I. Scagel, R. K. (Robert K.) II. Canada. Forestry Canada. III. British Columbia. Ministry of Forests. IV. Canada-British Columbia Forest Resource Development Agreement. V. Canada/BC Economic & Regional Development Agreement. VI. Series.

SD397.E5E33 1991 634.9'75256 C91-092129-6

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Produced and distributed by the Ministry of Forests, Research Branch.

For additional copies and/or further information about the Canada-British Columbia Forest Resource Development Agreement, contact:

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ABSTRACT

Seedling mortality and performance of 2+0 PSB 313 Engelmann spruce were examined annually for 5 years in high ESSFmw and mid-elevation MSdm of the Lillooet Forest District. Although there were performance differences related to planting date, site-specific overwinter damage was the major factor determining survival and performance. Spring planting and mid-August planting dates in the ESSFmw consistently outperformed fall plantings. The MSdm2 sites experienced severe overwinter damage and unacceptable mortality. Overwinter damage was related to planting date and planting microsite. Later fall plantings experienced higher mortality than earlier plantings. Sheltered seedlings were less prone to overwinter damage than unsheltered seedlings. Recommendations are provided for time of planting and site preparation.

ACKNOWLEDGEMENTS

Funding for this project was provided by FRDA grants 3.06, 3.37, and 2.03, and B.C. Ministry of Forests funds for EP 997 and EP 980. George Zorn's initiative and continued support were a valuable contribution to these experiments. Gerry Davis, John Spence, Paul Bernardy, Chris DeWreede, Anna Scagel, Helmar von Hahn, and Jack Maze all contributed field work and site visits. Bob Mitchell helped establish the experiment and conducted ecological descriptions. Rob Brockley and Ed Elms established a fertilizer trial adjacent to our experiments that has yielded a valuable check on our results. Wolfgang Binder and Dave Robertson performed the RGP tests. Bruce Morton provided seedlings and enthusiasm. Bruce Fraser provided the initiative for the cost analysis.

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1 INTRODUCTION

1.1 Problem

In the late 1970's, as logging extended to higher elevations where little was known of the edaphic and climatic conditions, new logistical problems were encountered and alternatives to spring planting had to be considered. In particular, late snowmelt limited access to plantation for spring planting. Late season (summer or fall) planting represented an attractive, but largely unexplored reforestation strategy.

The initial experience with fall planting Engelmann spruce at high elevations in the Lillooet Forest District resulted in variable plantation performance. Experience in the Vancouver Forest Region and elsewhere has indicated similar survival and performance of spring and fall plantings (Krumlik 1984). Krumlik (1984) proposed a set of climatic and edaphic guidelines for acceptable fall planting programs (Table 1). Although these guidelines were untested, they represented a starting point for research into the reliability of fall planting high elevation sites.

TABLE 1. Recommended climatic and edaphic conditions for fall planting

Based on Cleary *et al.* (1978), Krumlik (1984) made the following suggestions that broadly circumscribe acceptable climatic and edaphic conditions for summer and fall planting:

1. Soil temperatures in the top 25 cm of the soil should be greater than 4°C.
2. Soil moisture in the top 25 cm of the soil should be greater than -1 bar.
3. Air temperature should be less than 18°C.
4. Wind speed should be less than 30 kph.

1.2 Background

The period immediately following snowmelt has been considered the most suitable time for planting tree seedlings (Table 2). Spring planting has been a reliable and feasible[1] reforestation strategy on low elevation sites. However, by the time high elevation sites could be accessed for spring planting, the weather was generally too hot and the soils too dry to permit growth before mid-summer moisture deficits occurred. "Spring planting" of high elevation sites was actually summer planting using seedlings that had been cold-stored for more than 6 months. The phenology of seedlings planted in the late spring (late May, early June) was delayed compared to that in natural spruce seedlings, and the planted seedlings had high moisture demands due to flushing at a time when temperatures were increasing and soil moisture was decreasing. Spring planting on high elevation sites was not as reliable or as feasible as on low elevation sites.

Fall planting at high elevations was originally considered for sites that were inaccessible because of late snowmelt (Table 2). Planting on these sites was postponed until the fall, when soil moisture increased and temperatures decreased. Operational fall plantings were first conducted in the late fall (early October) because of a concern for a lack of soil moisture and stock availability. Even though climatic and edaphic conditions were generally more suitable for earlier plantings, seedlings had often not set a bud and the plugs of container-grown stock were not cohesive enough to be used. Fall planting was considered as little more than "heeling in" – a way to avoid prolonged cold storage and expensive snow removal.

In the early 1980's, several events led to increased interest in fall planting. The development of the 2+0 container-grown stocktype to replace the more expensive 1+1 transplant stocktype meant large seedlings could be produced reliably, with a budset early enough to be used routinely in a summer/fall planting program. As the provincial reforestation program expanded, there was increased demand for container-grown seedlings. No longer was it possible to satisfy all the reforestation needs with just spring planting stock: the planting season had to be extended to plant all sites.

[1] Reliability and feasibility are used in the manner described by Klinka and Feller (1984).

TABLE 2. Advantages and disadvantages of spring and fall planting (Krumlik 1984)

Advantages of spring planting on low elevation sites:
1. Soil moisture is adequate for the seedlings' physiological demands.
2. Cool weather reduces the probability of damage by high temperatures and low relative humidities.
3. Early planting allows seedlings enough time to flush, develop root systems, and become well established before mid-summer soil and climatic moisture deficits.
Disadvantages of spring planting on high elevation sites:
1. Early planting is often not practical because access to sites is restricted by late snowmelt.
2. Seedlings must be kept in cold storage for extended periods of time, during which stored carbohydrates decline.
3. If planting is conducted too late, seedling phenology will be delayed compared to that in the naturals.
4. Seedling flush may coincide with the onset of moisture deficits and high temperatures.
Advantages of fall planting on high elevation sites:
1. Fall-planted seedlings still have active roots and may begin to establish a root system before winter.
2. Seedlings are partially dormant and have a high physiological resistance to desiccation, and they may be less prone to debilitation by site conditions.
Disadvantages of fall planting on high elevation sites:
1. If seedlings are not mature enough, they could be frost-damaged.
2. If seedlings are planted too late, they could be frost-damaged or frost-heaved.
3. Seedlings could be subject to increased browsing, as fall is a time of increased rodent foraging for overwinter food storage.

1.3 Objectives

This project was initiated at the request of Lillooet Forest District to investigate the inconsistency in plantation performance in the Lillooet Forest District. The major objective was to examine the reliability of summer, fall, and spring planting of Engelmann spruce over a variety of high elevation sites. A supplemental objective was to describe the climate of high elevation reforestation sites.

2 METHODS

2.1 Sites

Five freshly logged sites were chosen in the Hurley River drainage, south of Goldbridge (Figure 1). Site descriptions and histories are given in Table 3. The sites represent the range of elevational, edaphic, and site preparation conditions found in the ESSFmw and MSdm2 biogeoclimatic zones (Lloyd *et al.* 1990) in the Hurley River drainage, and available for planting during 1985. All sites, with the exception of MS2 were broadcast slashburned. Each site was edaphically uniform. The preferred planted species on all sites was Engelmann spruce (Lloyd *et al.* 1990; Table 3).

A silvicultural risk assessment was prepared for each site (Table 3), based on site factors and taking into consideration the reviews of Alexander and Shepperd (1984), Alexander (1986), and Stathers (1989). Because of their high elevation and the large size of the clearcuts, all sites are potentially frost-prone. The microclimate associated with the mesotopographic position and lower elevation of the MS sites predisposes them to increased silvicultural risk for Engelmann spruce compared to the higher elevation ESSF sites. The topographic shading and aspect of the ESSF sites suggested that they may have a shortened growing season and may not be as productive as the MS.

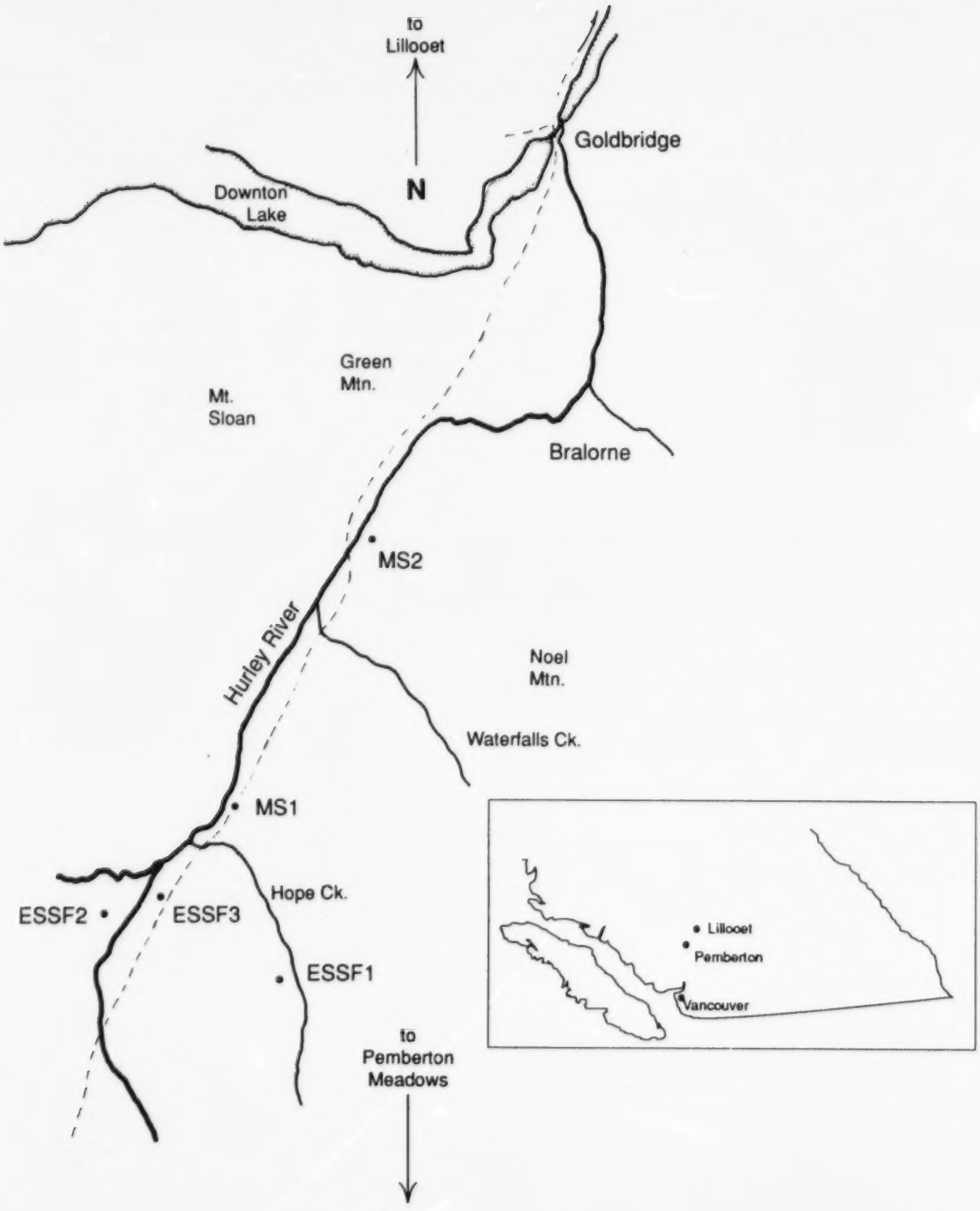

FIGURE 1. Site locations in the Hurley River drainage.

TABLE 3. Site descriptions for experimental sites in the Hurley River drainage

Site description:	SITE				
	ESSF1	ESSF2	ESSF3	MS1	MS2
Biogeoclimatic zone	ESSFmw	ESSFmw	ESSFmw	MSdm2	MSdm2
Elevation (m)	1341	1250	1250	1128	1097
Moisture regime	3–4	3–4	4	4	4–5
Nutrient regime	C	B	C–D	A–B	D
Aspect (°)	25	70	250	FLAT	FLAT
Slope angle (°)	15	20	10	FLAT	FLAT
Latitude	50°39'	50°40'	50°40'	50°43'	50°44'
Longitude	123°00'	123°01'	123°01'	122°58'	122°57'
Site location	M. Slope	V. bottom	L. Slope	V. bottom	L. Slope
Soil texture	SL	SL	SL	fSL	SL
Soil depth (m)	0.5	.3–1	.3–1	> 1	> 1
Site history:					
Logged	1984	1984	1984	1984	1984
Slashburned	BURN	BURN	BURN	BURN	UNBURN
Planting time (hr/100)	1.9	1.3	2.8	1.5	1.8
Opening size (ha)	16	5	14	96	18
Management goals:					
Preferred species[a]	Se	Se	Se	Se/Pli	Se/Pli
Minimum stocking (K stems/ha)[a]	0.7	0.7	0.7	.7/.8	.7/.8
Target stocking (K stems/ha)[a]	1.2	1.2	1.2	1.2/1.4	1.2/1.4
Regeneration delay (yr)[a]	6	6	6	6	6
Minimum free growing (yr)[a]	11	11	11	11	11
Maximum free growing (yr)[a]	15	15	15	15	15
Planting season	MAY–OCT	MAY–OCT	MAY–OCT	MAY–OCT	MAY–OCT
Silvicultural risk assessment:					
1. Frost incidence:					
Site position – catabatic flow	YES			YES	YES
Site conditions – clear sky	YES	YES	YES	YES	YES
Site conditions – frost pocket				YES	YES
Site macroclimate	WET	WET	WET	MED	DRY
2. Wind damage:					
Valley bottom parallel to prevailing wind				YES	YES
3. Vegetation competition:					
Vegetation – possible competition	NO	HERB	FWEED	FWEED	GRASS
4. Other factors:					
Aspect related snow duration – snow press	LATE				
Spring access problems	YES	YES			
Blackened surface – lethal temperatures	BLACK	BLACK	BLACK	BLACK	
Perched, intermittent water table				YES	YES
High winds – desiccation, snow ablation				YES	YES
Topographic shading	YES			YES	YES
Mid-summer drought				MAYBE	MAYBE

[a] Lloyd *et al.* 1990.

2.2 Seedlings

The history, development, and status of the container-grown 2+0 stocktype merits discussion. In the early 1980's, 1+0 container-grown stocktypes became popular but required greenhouse facilities that were expensive and space-limited. Nurseries were unable to accommodate all of the sowing requests for container-grown stock. As a result, the 2+0 container-grown stocktype was developed as an alternative to the 1+0 container-grown, 2+0 bareroot, and transplant stocktypes. Compared to the 1+0 container-grown crop, the 2+0 crop does not require expensive greenhouse facilities and can be sown much later than the 1+0 crop — attributes that are economically attractive to forest nurseries. The 2+0 container-grown stocktype is also far less expensive than a comparable transplant stocktype. Its major disadvantage, however, is the potential overwinter frost damage that can occur to the crop in an open nursery compound.

Since the start of the experiment reported here, the culture and quality of 2+0 container-grown stocktype have changed substantially. Furthermore, stocktypes are now available in a greater range than in 1985, and greenhouse space, heating, CO_2 enrichment, and cultural experience have increased. As well, early-sown, 1+0 container-grown stocktypes are more widely available today as mid-summer planting stock. If sown early enough, 1+0 container-grown stock can now be delivered for summer planting by mid-July rather than mid-September.

Just as the cultural conditions and crop cycle have changed, so have handling, packaging, transportation, and on-site storage practices. Planters, supervisors, nursery workers, and transportation companies have acquired more experience with summer- and fall-planted stock.

The seedlings used in our experiment were all 2+0 PSB 313a Engelmann spruce grown at a single nursery in the British Columbia Lower Mainland. The seedlings were part of one of the first 2+0 container-grown crops produced on a commercial scale. The seedlot (Se 8303) used was locally collected in the ESSFmw, Hurley River drainage. The particular crop was selected because of the uniformity in stock height and color, large root collar diameter and well-developed foliage color.

Morphological descriptions of a sample of the seedlings used are given in Table 4. This stock was morphologically larger than the Ministry of Forests' stock specifications. Over the experimental period, there was a progressive change in the root mass. In the first two plantings, the plug cohesion was so poor that the plugs fell apart easily in the planting bags. In the later plantings, the plugs became progressively more root-bound and plug cohesion increased.

TABLE 4. Description of stock used in the fall and spring planting. Morphological description of stock based on a sample of 30 seedlings taken from frozen storage, December 1985.

Morphological trait	Mean	Standard deviation
Height (1985)	19.4	± 3.5 cm
Height (1984	13.1	± 2.9 cm
Root collar diameter	4.3	± 0.6 mm
Root weight	1.4	± 0.5 g
Shoot weight	2.3	± 0.6 g
Stem weight	1.1	± 0.3 g
Needle weight	1.2	± 0.4 g

Root growth potential (RGP) tests were performed on a sample of seedlings taken from the nursery immediately before each planting. The tests were aimed at measuring "seedling quality" (Burdett 1987) rather than seedling dormancy (Burr *et al.* 1987). The RGP test used was the standard Ministry of Forests pot test, in growth chambers with conditions of 25°C day and 20°C night temperature for 2 weeks (Binder *et al.* 1990).

Root growth potential changed progressively over the planting period (Figure 2). Root system activity was high during August and declined rapidly in early September. The variation of RGP within the crop was very large for the first two planting dates, but decreased along with root activity. This change paralleled an increase in root mass and plug cohesion. Burr *et al.* (1987) found a similar decline of RGP with season in their work with Engelmann spruce.

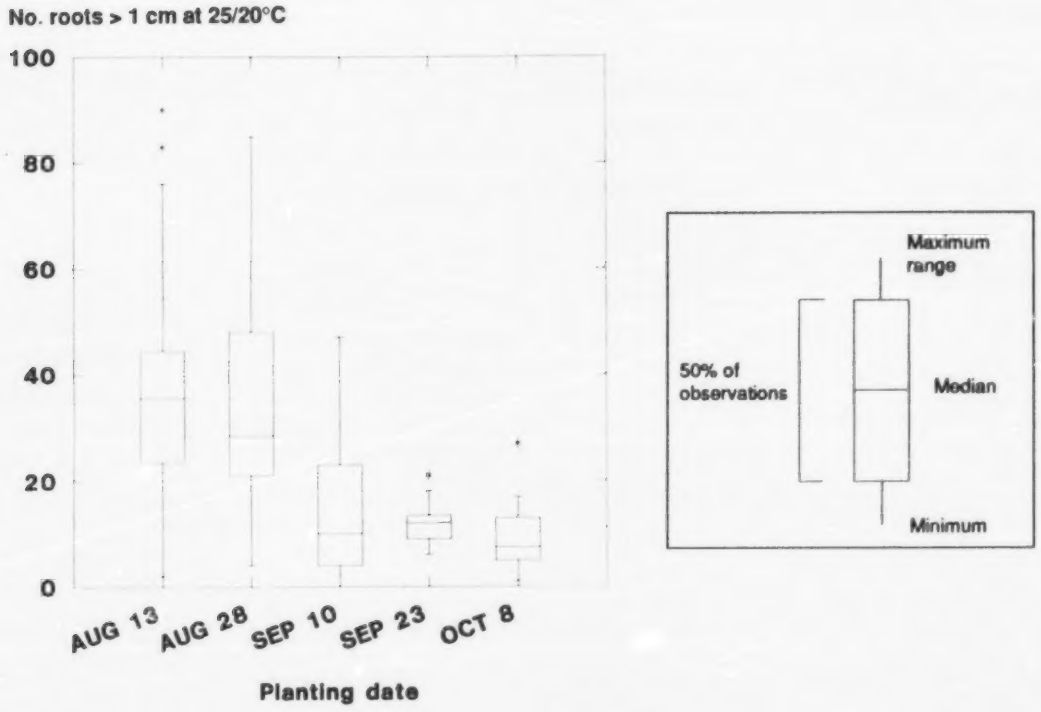

FIGURE 2. RGP of planting stock used in the five fall planting dates 1985. Box plots of number of new roots greater than 1 cm long. Test temperature was 25°C/ 20°C day/night growth temperature conditions for 2 weeks. Box plot interpretations are described in the data analysis section. The inset describes the graphic conventions used in a box plot.

2.3 Planting

Seedlings were planted on six dates from August to October 1985 and again in late May of 1986 immediately after snowmelt at the ESSF sites (Table 5). The planting dates covered a wider range of times than the usual operational planting. One hundred seedlings were planted on each date at each site — a total of 3000 seedlings — under a range of planting conditions (Figure 3).

TABLE 5. Planting times used in the experiment

Planting #		Planting dates
Summer planting	1	August 13, 1985
	2	August 28, 1985
Fall planting	3	September 10, 1985[a]
	4	September 23, 1985
	5	October 8, 1985
Spring planting	6	May 24, 1986[b]

[a] Commercial planting established at the same time on ESSF1, ESSF2, ESSF3, and MS1.
[b] Commercial planting established on blocks adjacent to MS2.

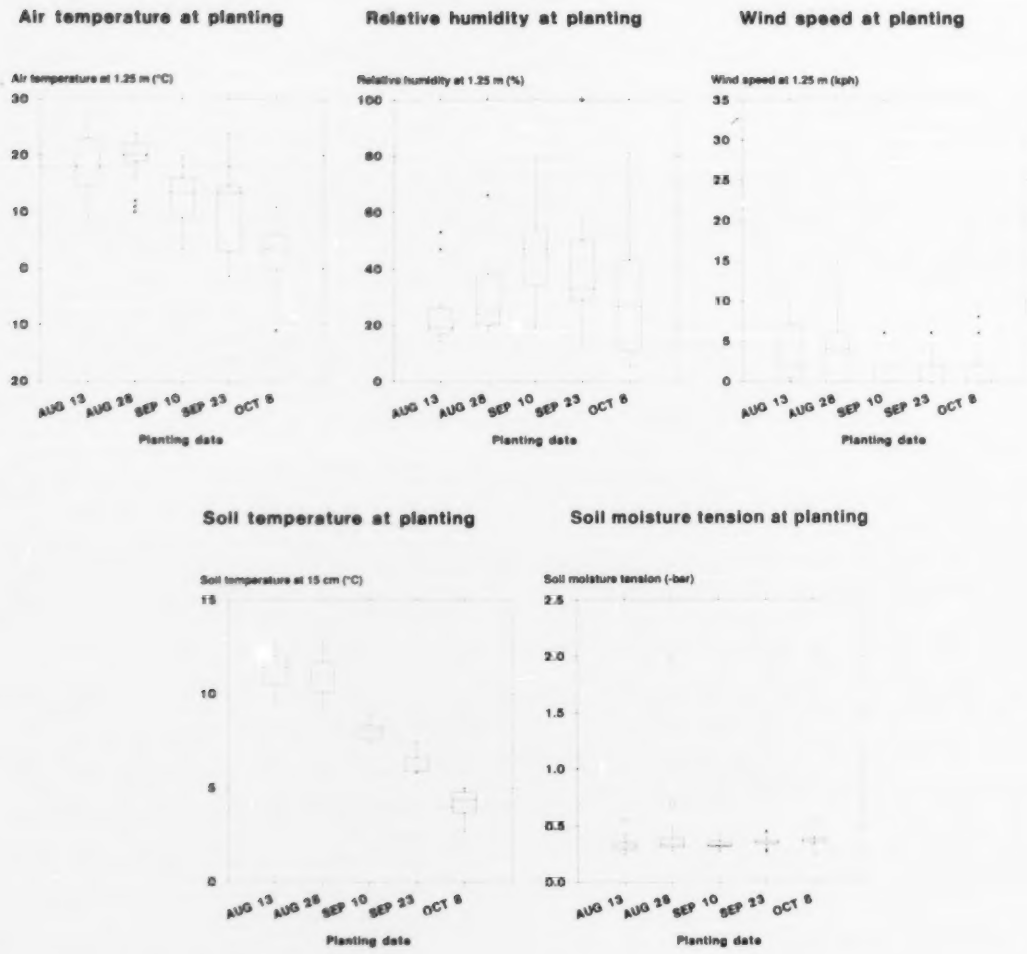

FIGURE 3. Site climatic and edaphic conditions for five fall planting dates 1985. Box plots show the range of climatic variables during actual planting. Results have been pooled over all sites at each planting. Horizontal dashed lines through the box plots indicate limits of acceptable climatic and edaphic conditions listed in Table 1. These data represent the conditions measured during planting; they do not cover the climatic conditions experienced after planting. Similar data are not available for the spring planting.

The climatic conditions during planting were not restricted to the criteria in Table 1. Planting seedlings under other climatic conditions was intentional to allow us to determine the limits to summer and fall planting. Climate monitoring (Figures 4–6) indicated that soil surface and seedling temperatures were warmer than the air temperatures shown in Figure 3. Although the planting conditions were harsh compared to standards (Table 1), at least 30 mm of rain fell between plantings.

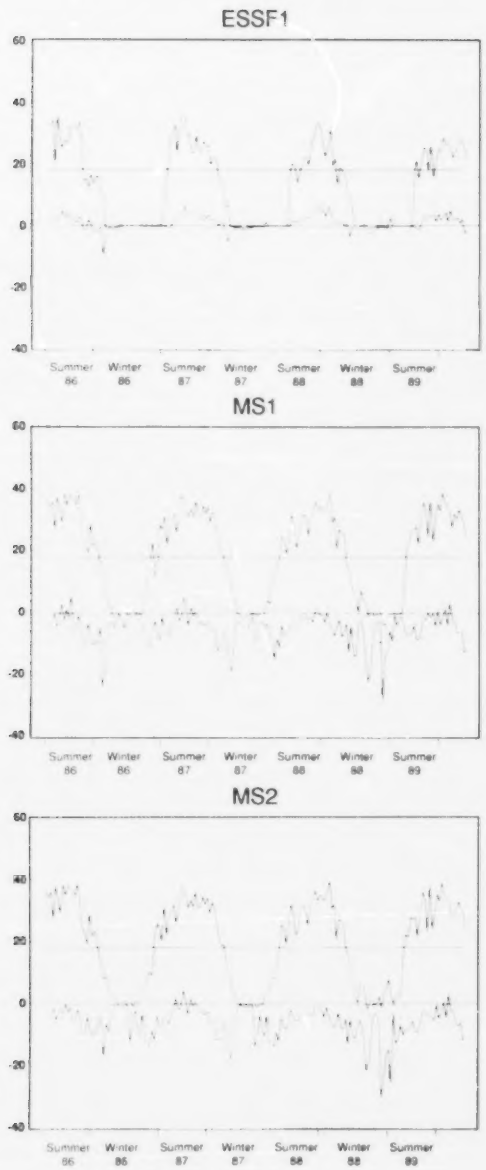

FIGURE 4. Air temperatures at seedling height (20 cm) for three experimental sites. Lines represent weekly maximum and minimum temperatures for 4 years. A reference line at 0°C is given. The reference line at 18°C represents the upper limit of accepted air temperatures for planting (Table 1). Sites are arranged in order of decreasing elevation. Notice that the maximum temperature throughout the winter remains close to 0°C, and that the difference between minimum and maximum temperatures is small. This is due to the depth of the snowpack exceeding the height of the temperature sensor.

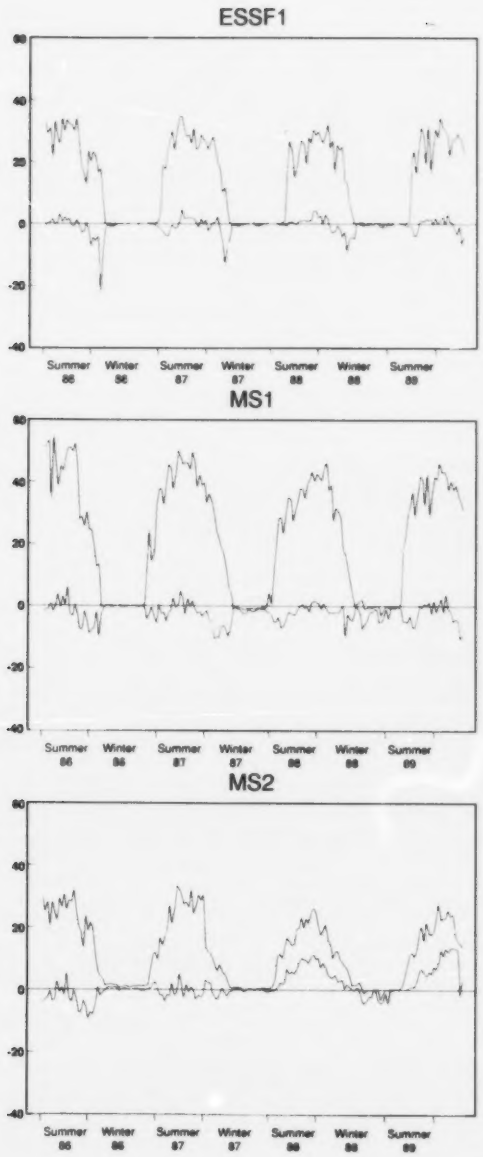

FIGURE 5. Soil surface temperature at three experimental sites. Lines represent weekly maximum and minimum temperatures for 4 years. A reference line at 0°C is given. Sites are arranged in order of decreasing elevation.

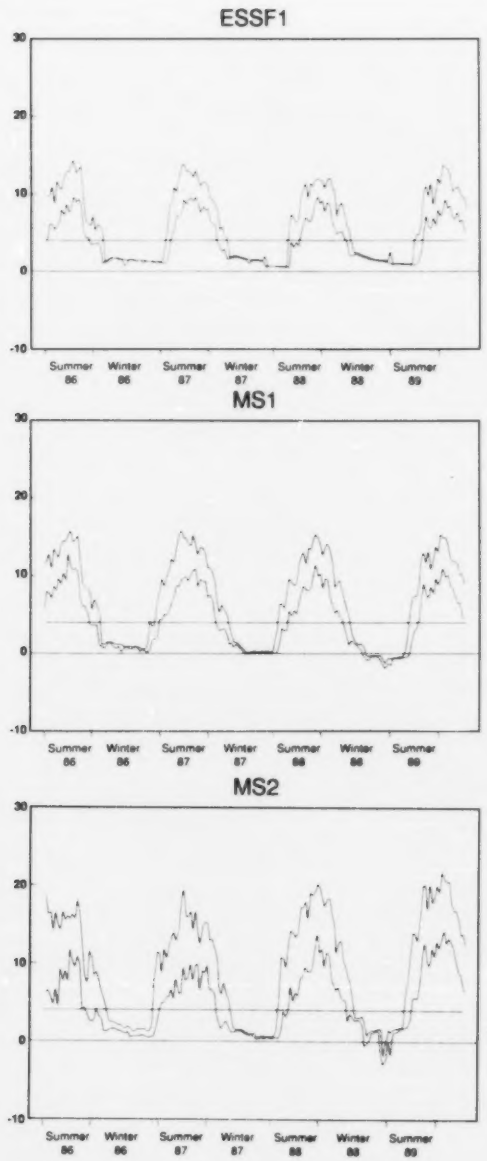

FIGURE 6. Soil temperature at 15 cm at three experimental sites. Lines represent weekly maximum and minimum temperatures for 4 years. A reference line of 0°C is given. The reference line at 4°C is the minimum soil temperature recommended in Table 1. Sites are arranged in order of decreasing elevation. Notice the yearly variation in temperature is greatly reduced compared to air and soil surface temperatures (Figures 4 and 5).

The most stressful planting conditions — very low relative humidity, high temperatures, and relatively high wind speeds — were encountered at the first planting date, although soil moisture and temperatures were acceptable. The first two plantings also occurred at the time when the RGP test suggested the seedlings were the most active and potentially injury-prone. The soil and air temperatures for the latest fall planting were very low and frost damage or frost-heaving was expected.

Because seedlings used for summer and fall planting are physiologically active, (unlike frozen-stored spring planting stock), they require special care during transport, lifting, and planting. To isolate plantation effects from cultural and handling conditions, we ensured that all seedlings were transported to the planting site in the containers they were grown in, and then lifted and culled on-site immediately before planting. This culling reduced the variation in height and root collar diameter in the crop.

All trees were shovel-planted. Planting occurred throughout the day, regardless of weather and site conditions, and seedlings spent no more than 2 hours in planting bags (Table 3). The planting rate was considerably slower than operational speeds because of the tight spacing used.

2.4 Climate

Climate was monitored for two reasons: to document planting conditions, and to monitor seedling climate for 4 years after planting. Planting conditions (wind speed, air and soil temperature, and soil moisture) were measured with hand instruments. Continuous monitoring employed equipment and techniques described by Spittlehouse (1989). Further description of the equipment, measurement techniques, and data manipulation are provided in Spittlehouse and Goldstein.[2] Although continuous monitoring was initiated in 1985, reliable data were not obtained until spring 1986.

The results of continuous monitoring are presented in Figures 4–6 as weekly summaries for each of three sites representing the elevational range of sites in the experiment. Portions of the climate monitoring are also described by Spittlehouse and Stathers (1989) and Stathers (1989). In Table 3, the monitoring results were compared to the silvicultural risk assessments.

Seedling air temperature

Air temperatures were measured at the seedling height (20 cm) (Figure 4). The most notable feature of all sites was that diurnal temperature variation at this height exceeded 40°C. Freezing temperatures occurred on any day of the year on any of these sites.

During the winter months, however, the temperature variation at 20 cm was markedly subdued compared to the rest of the year. This reflects the insulating effects of snow which, at mid-winter, can pack to between 75 and 150 cm. The low temperatures periodically experienced in some winters were due to ablation of snow (by wind redeposition and sublimation) and subzero freezing temperatures penetrating the snowpack. The sites in the MS are considered to be at risk from snow ablation, as the valley bottom is parallel to the prevailing wind (Table 3).

Although ESSF1 is the highest elevation site, the sheltering north aspect and topographic shading reduced the diurnal temperature variation there to less than 35°C. Summer frosts were not as frequent as on the MS sites, either. The ESSF sites also appeared to be above the elevation and topographic position of winter temperature inversions.

Winter frosts at the MS sites are markedly severe compared to those in the ESSF. In particular, the -25°C recorded in the winter of 1988–89 on the MS sites did not occur on the ESSF sites. In the previous winters (1986–87, 1987–88), extremely cold temperatures were only encountered in either late fall or early spring — never in mid-winter.

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[2] Spittlehouse, D.L. and M.J. Goldstein. 1991. Climate of clearcut sites of the Coast Interior Transition Zone. B.C. Min. For., Victoria, B.C. In preparation.

Soil surface temperature

The diurnal amplitude of soil surface temperatures (Figure 5) exceeded 40°C and is larger compared to the amplitude of the seedling height temperatures (Figure 4). Because of the blackened soil surface and lack of topographic shading (Table 3), MS1 and ESSF1 routinely experienced soil surface temperatures greater than those recorded at MS2. Although slashburned, ESSF1 did not experience the same 40°C diurnal fluctuation as MS1 because of the north aspect, topographic shading, and mesotopographic position.

Maximum soil surface temperatures increased dramatically following snowmelt. Throughout the growing season, the maximum soil surface temperatures exceeded 18°C. Potentially lethal soil surface temperatures for Engelmann spruce (Seidel 1986) were recorded on all sites in all years, even during the planting. These lethal temperatures occurred within weeks of snowmelt regardless of the soil surface conditions.

The insulating effect of even a shallow snowpack is well illustrated in a comparison of Figure 4 to Figure 5. Soils were significantly insulated from very cold air temperatures at MS1 by the snowpack. At MS2, however, there was not enough snow to insulate the soil surface from severe freezing temperatures. The effects of mid-winter snow ablation are particularly well illustrated by the soil surface temperatures during the 1988–89 winter at MS2.

Soil temperature

Soil temperature was measured at 15 cm, the depth of the seedlings' roots (Figure 6). Diurnal soil temperature variation was much lower (5°C; Figure 6) than air temperature variation (40°C). For most of the growing season, soil temperatures were greater than the recommended 4°C (Table 1). By the time these sites are accessible for spring planting, soil temperatures were above the 8°C minimum threshold for root growth indicated by Smith *et al.* (1987). At no point during the growing season did soil temperatures ever reach the root growth optima of 22°C suggested by Binder *et al.* (1990). Soil temperatures were not elevated on the slashburned sites.

Freezing soil temperatures occurred during the winter months when the insulating snowpack was lost from the site. Mid-winter snow loss is apparent on the MS sites in winter 1988–89; repeated mid-winter snow ablation was indicated by low soil surface temperatures.

Soil moisture

Soil moisture deficits have not occurred at the MS1 or ESSF1 sites (Figure 7). What appeared to be a mid-winter moisture deficit recorded at MS1 during winter 1988–89 was actually a freezing effect on the measurement instrument, a gypsum block. On these two sites, even during the warmest periods, soil moisture tensions less than -1 bar were rarely recorded.

The MS2 site was a different situation. Serious moisture deficits have occurred on this site every summer between mid-July and mid-September (after seedling bud-set). The frequency and severity of drought here may have been underestimated because of the effect of the soil texture (Table 3) on the recording ability of gypsum blocks used to measure soil moisture deficits.

Rainfall

Rainfall was frequent, once every 10 days, though the quantity of precipitation differed substantially between sites (Figure 8). On average, ESSF1 receives 30% more rainfall during the growing season than MS2. The total rainfall and the coarse-textured soil at MS2 indicate that severe moisture deficits occurred on this site.

Precipitation has increased on all sites since the start of the experiment. The large year-to-year variation in precipitation therefore limits the extrapolation of the seedling survival and performance results to other plantations established in wetter or drier years.

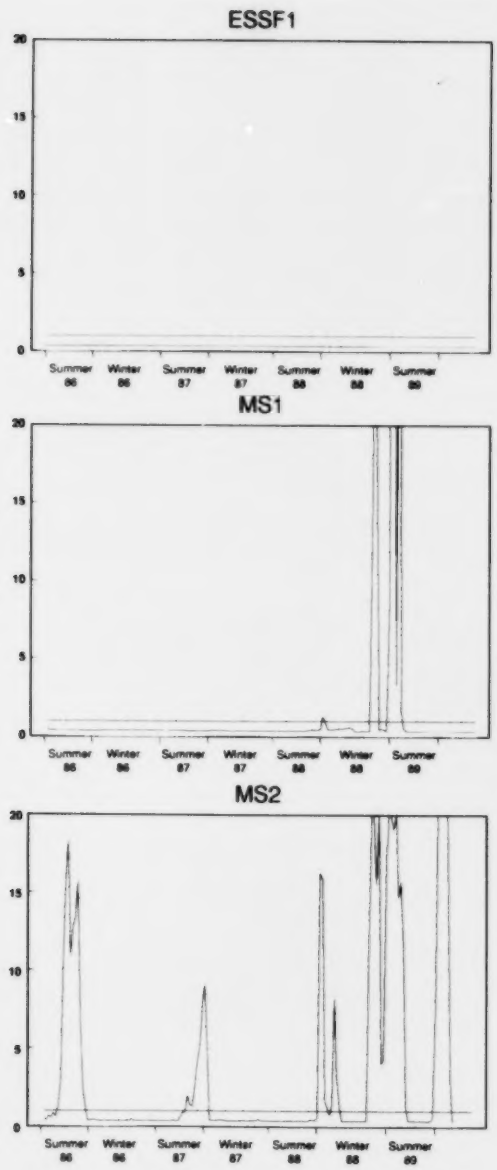


FIGURE 7. Soil moisture at 15 cm at three experimental sites. Line represents weekly mean soil moisture at 15 cm depth. The reference line at -1 bar is the maximum soil moisture deficit recommended in Table 1. The permanent wilting point is -15 bars. Sites are arranged in order of decreasing elevation.

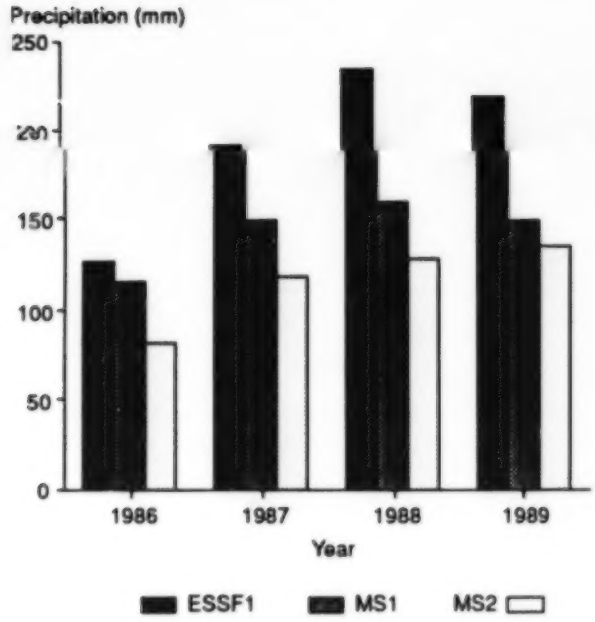


FIGURE 8. Growing season rainfall at three experimental sites. Bars are the total rainfall over the growing season (end of May and the start of October). Sites are arranged in order of decreasing elevation.

2.5 Data Collection and Analysis

Data were collected on each tree by a stake-point technique (Stein 1978). Although such a sampling strategy is expensive to establish and tedious to maintain, these data provide analytic flexibility that cannot be achieved by independent random sampling or reconstructive assessments. Stake-point sampling also allows detailed photographic records to be kept of individual trees.

To discriminate between summer and winter damage, condition and form of seedlings were recorded every spring and fall. Seedling condition code was determined on an admittedly subjective basis. Growth measurements were also taken every October (Table 6). Variation of data is presented as box plots.

A cost analysis of the different planting dates (Appendix 2) illustrates the practical significance of the survival and growth results observed in the experiment. This analysis is not meant to be an exhaustive accounting of costs, but rather a general estimate of the realistic costs associated with preparing sites, planting seedlings, and carrying the plantation through to the final assessment period.

Cost comparisons are only as good as the assumptions they are based on. Details of the base prices, calculations, and assumptions used in the cost analysis are provided in Appendix 2.

TABLE 6. Measurements, condition, and form variables used

Character	Unit
Measurements:	
Leader length	cm
Total height	cm
Diameter at base of 1986 increment	mm
Lateral length	cm
Seedlings condition: GOOD[a]	
Lammas growth	
Multiple leader	
Browsing	
Gall aphid infestation	
Stem fork	
Seedling condition: POOR[b]	
Frost damage	
Leader dieback	
Terminal bud abortion	
Chlorosis	
Needle loss	
Snowpress	
Extruded plug	
Seedling condition: DEAD	

[a] To be classed as "good condition" a seedling had to be free of defects listed under "poor condition." Good condition was still assigned if the seedling had one or more of the conditions under "good condition."

[b] To be classed as "poor condition" a seedling had to have at least one of the defects listed under "poor condition."

3 RESULTS AND DISCUSSION

3.1 Mortality and Damage

Overwinter damage

All seedlings were inspected in late October and early November 1985 to determine whether any had died in the planting year. Climatic conditions during this survey were cool and a heavy snowfall occurred. Nearly all seedlings appeared healthy at this time and, with the heavy snowfall, we predicted that they would survive. Over all sites there was less than 0.5% mortality. The seedlings that had died had been predisposed to mortality because of planting mistakes. Although extreme low temperatures (-25 to -35°C) occurred in mid-November 1985, the seedlings were not exposed because they were under an insulating snowpack.

On adjacent commercial plantations on all sites, established at the same time as our third planting, and using the same seedlot and stocktype as in our experiments (Table 5), 15% of the seedlings died by the end of October 1985. The dead seedlings appeared to have been desiccated. Planting quality, microsite selection, and transportation and handling may have contributed to the difference in mortality. These results show the utility of establishing supervisor check plots as a strategy to identify plantation performance problems.

In the winter of 1985–86, seedlings on the MS sites suffered a 50% incidence of overwinter damage (Figure 9). Both chlorotic foliage and poor needle retention were apparent (Plate 1a; see also illustrations in Orlander *et al.* [1990]). These morphological conditions are similar to those reported in spruce and attributed to solarization (Ronco 1970a, 1970b, 1972; Lundmark and Hüllgren 1987; Orlander *et al.* 1990).

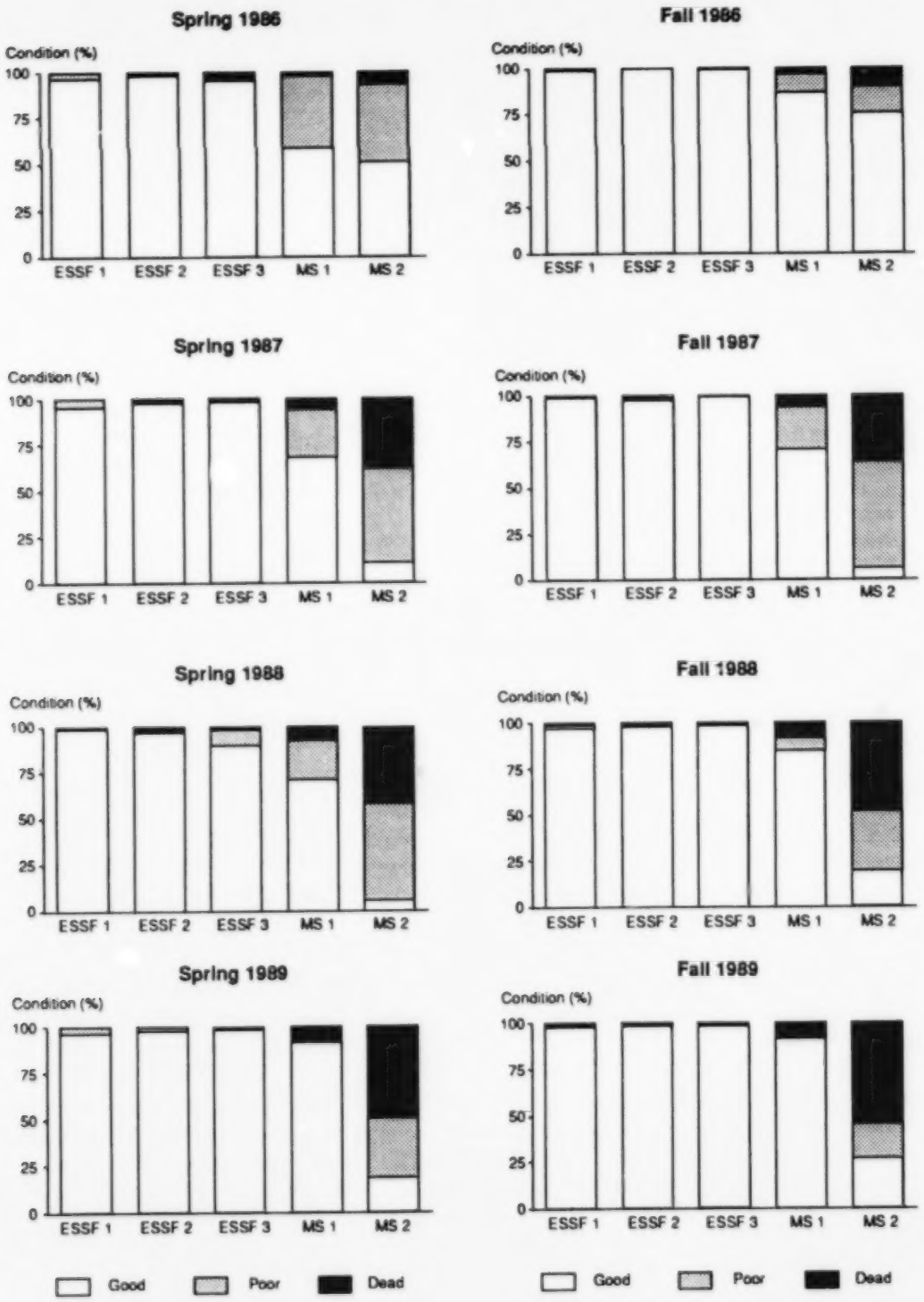


FIGURE 9. Spring and fall seedling condition for all five experimental sites. Three condition classes are represented: good, poor, and dead (Table 5). Mortality and poor performance are due to frost and desiccation-related damage as shown in Plates 1–3 (pages 22–24). All planting dates are pooled for each site. Sites are arranged in order of decreasing elevation.

Rikala and Repo (1987) have reported similar conditions in pines. In addition to the foliar symptoms, apical buds and subtending whorl and interwhorl buds had been damaged or killed. In some cases, bud death was accompanied by leader dieback. In severe cases, pitch had exuded from stem lesions. In nursery crops this sort of damage has been referred to as "winter burn" or foliar desiccation (Cordell *et al.* 1989).

The resultant flush from damaged seedlings was very small. Frost-heaving of plugs also occurred on MS sites, and was most pronounced on seedlings that were not planted close to slash or otherwise sheltered to the south. Where sheltering by slash was only partial, a "trim" line was evident on the seedlings (Plates 1a, 2a, page 22, 23).

Most of the mortality in the ESSF occurred in the first year and was independent of planting date. Overwinter damage in the ESSF has been severe.

Overwinter damage was the principal cause of mortality on the MS sites. Mortality has continued to occur past the establishment year and is strongly related to planting date. Mortality at MS1 stabilized in 1989, but seedlings at MS2 were severely damaged and continued to die (Figure 9). This delayed mortality illustrates the need for more than a first-year survival survey; follow-up surveys are also necessary.

The relationship between seedling condition in spring 1986 and planting date on the MS sites is illustrated in Figure 10. The later the planting, the more seedlings were damaged over the winter. Planting date related effects persisted at MS1 through 1987, with the spring-planted seedlings exhibiting the least damage. From these results, the optimum time for fall planting in the MS appears to be either early spring or late August - early September. Summer planting should not be conducted if soil moisture is below -1 bar.

Overwinter damage occurred again in winter 1986–87 but was largely restricted to MS2 (Figure 10). There did not appear to be any relationship between the occurrence of overwinter damage in 1986–87 and the planting date.

The extent and severity of damage in winter 1985–86 and again in 1986–87 led us to expect high mortality among the damaged seedlings. In fact, we were surprised at how few of the severely damaged seedlings died. Although the growth of damaged seedlings remained poor (Plate 3, page 24), most eventually recovered (Plates 1c, 2c, page 22, 23).

By 1989 the seedlings had adjusted to the site and could tolerate winter conditions. The low temperatures of the winter of 1988 (Figures 4–6) did not damage seedlings, although the foliar nutrient status of the planted trees and naturals were almost equal by 1989.

These results show that most seedling damage on these sites occurred during the winter. An evaluation of site characteristics and assessment of risk (Table 3) can help predict damage. Growing season conditions and stresses may predispose seedlings to winter damage.

Naturally occurring spruce and pine and planted lodgepole pine did not display the damage from frost and desiccation experienced by planted spruce on the MS sites. This suggests that nursery-grown spruce may somehow be predisposed to frost and winter damage. Foliar nutrient analysis and the lack of root growth by seedlings support this position.

Although Engelmann spruce is currently the recommended species in the MS on this ecosystem association (Lloyd *et al.* 1990), planting it is not a viable option on these sites because of its high mortality, poor performance, and repeated frost damage. Lodgepole pine is better able to endure the exposure, drought, and cold temperatures of these sites and silvicultural systems. Planting lodgepole pine as a nurse crop to make the site more suitable for a fill-planting or natural seeding-in of Engelmann spruce may be worth considering.

Establishing this experiment in a different year could have resulted in entirely different results because of the year-to-year variation in winter conditions and growing season precipitation.

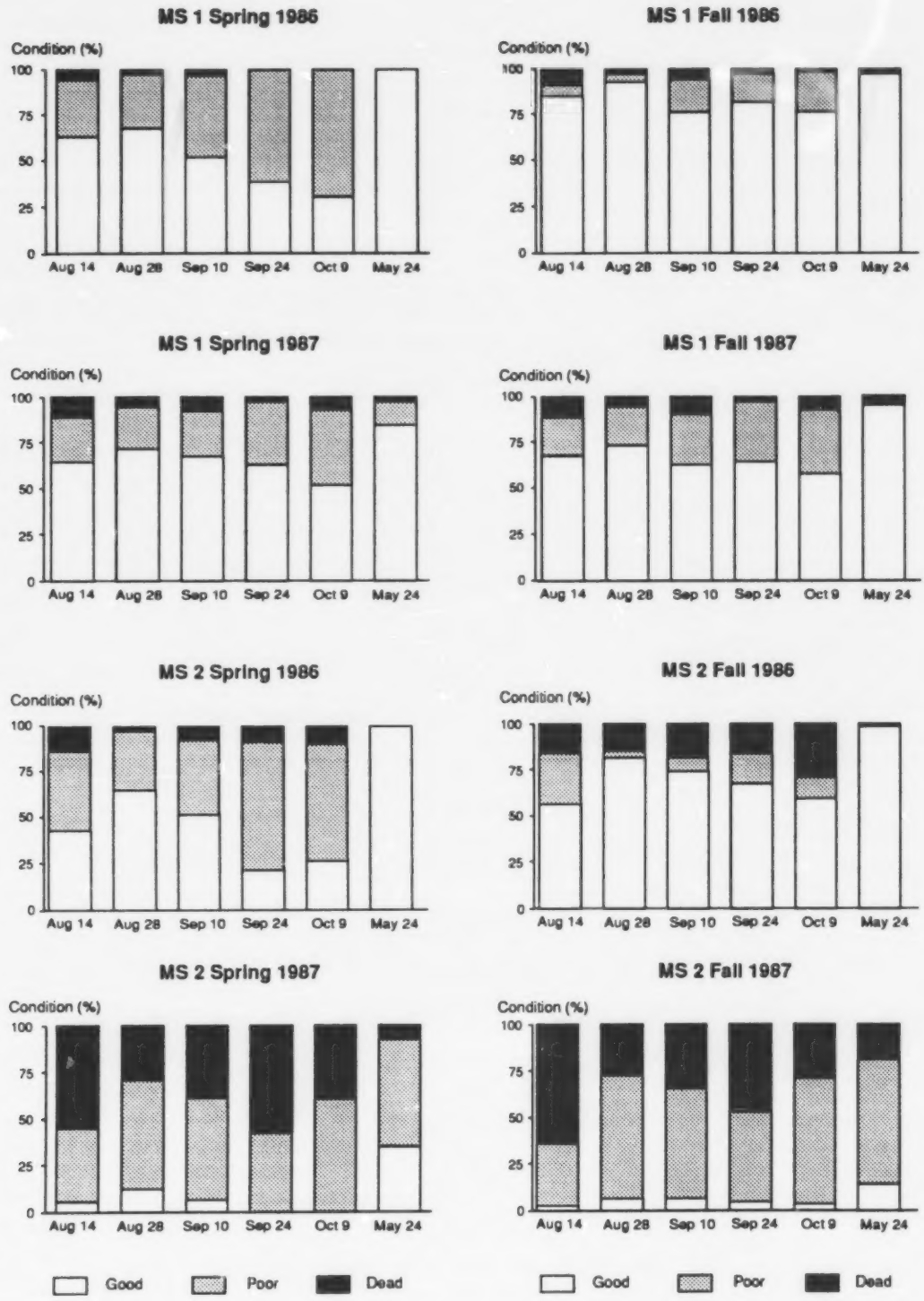


FIGURE 10. Spring and fall seedling condition for all planting dates on the MS sites. Three condition classes are represented: good, poor, and dead (Table 5). Mortality and poor performance are due to frost and desiccation-related damage as shown in Plates 1–3 (pages 22–24). Planting dates arranged in calendar order.

Spring frost damage

Frost damage to newly flushed shoots frequently damages planted spruce (Ronco 1972; Stathers 1989). Frost damage to newly flushed shoots was observed in 1986 and 1987 at the MS sites. Particularly severe frost damage affected commercial plantations planted in May 1985 on the MS sites. Spring frost damage to freshly flushed shoots was different from overwinter damage. Shoots elongated normally until they were frosted and the entire flush died (Stathers 1989). Such damage to newly flushed shoots was not observed on ESSF sites.

Snow press

Scagel *et al.* (1989) found considerable snowpress damage to seedlings on high elevation coastal and transition plantations. Only minor snowpress was found and it was restricted to ESSF1, where small pieces of slash had rolled onto seedlings or cured vegetation had pressed them. The lower specific gravity of the snow and shallower depth of snowpack may have contributed to lack of snowpress (Scagel *et al.* 1989).

3.2 Growth

Site differences are the most important factors contributing to variation in seedling growth (Figure 11). Both among-site and within-site variations have continued to increase.

Growth curves for individual sites are given in Appendix 1. For each year, the largest difference between sites is between MS2 and ESSF2. The diameters of seedlings at MS1 are considerably larger than at the other sites. The consequences of the increasing variation within sites for the ultimate crop have been noted by Vyse (1981). More of a stand's volume becomes carried by fewer trees.

There is a consistent trend evident on all sites: the best performing planting was the spring planting; the worst was the latest fall planting (Figure 12). The trend is particularly well expressed by diameter growth, where there was a 4 mm difference between the best and worst planting dates. The earliest planting in August was similar to the spring planting; later summer and fall plantings gradually declined in performance. The improved performance of the earliest fall planting of hot-lifted stock has been frequently reported in other studies of fall planting (Krumlik 1984).

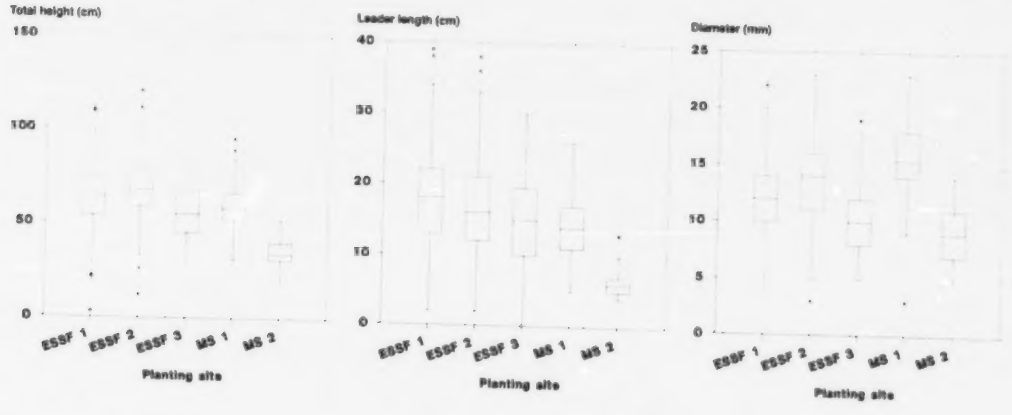


FIGURE 11. 1989 seedling growth measurements for all sites. Box plots of total height in 1989, 1989 leader length increment, and diameter. Data are for individual sites pooled over all planting dates. Sites have been arranged in order of decreasing elevation.

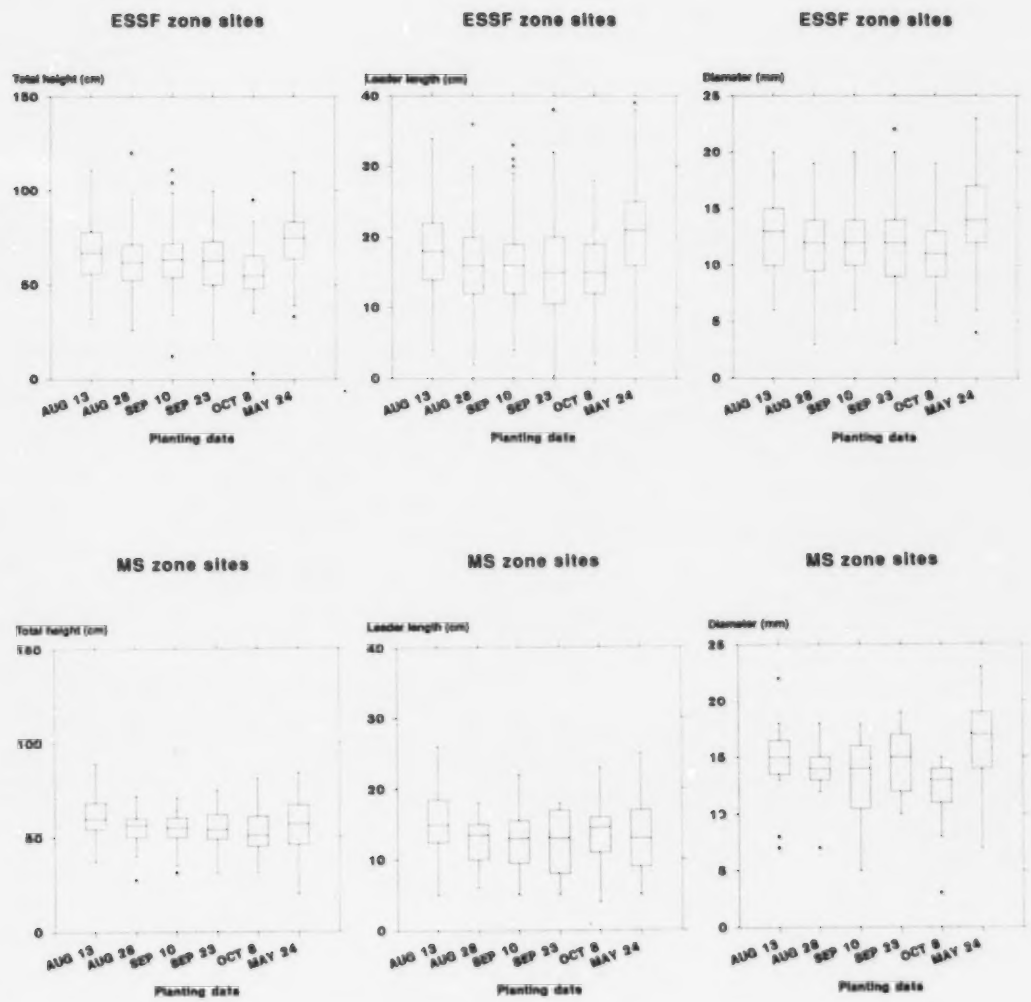


FIGURE 12. 1989 seedling growth measurements for all planting dates. Box plots of total height, 1989 leader length, and diameter for individual planting dates are pooled over all sites within each biogeoclimatic zone. Planting dates have been arranged in calendar order.

On the ESSF sites, the difference between best and worst plantings was as much as 18 cm total height in 1989. However, along with the increased growth there was increased variation of growth, which obscures the mean differences.

An unexpected result was that planting date is influencing current leader growth. Apparently the initial slight advantage associated with the spring planting (less than 2 cm in the first growing season, 1986) and the earliest fall planting continues to increase 4 years after planting. The persistence and increase of initial slight differences is consistent with the results of long-term studies on a variety of species, stocktypes, handling, and site treatments (Mullin 1974, 1980; Thompson 1974; Krumlik and Bergerud 1984; Pollack and LePage 1986; Sloan 1989; Pendl *et al.* 1990). The absolute value of the differences in height has been increasing and these differences may eventually become economically important.

3.3 Roots

Excavation of seedlings in late October and early November 1985 indicated that the pattern of root growth (Figure 13) from the plugs was similar to the change in RGP (Figure 2). Root growth was largest on seedlings from the earliest planting and decreased with the later planting dates. Representative seedlings are given in Plate 4 (page 24). In all instances the only root growth was at the bottom of the plug.

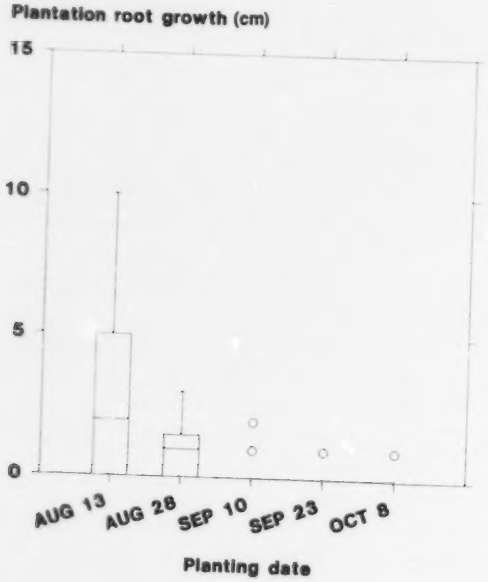


FIGURE 13. Root growth during the establishment season for fall planting dates in 1985. Root growth expressed as the mean length of roots grown in the field by the end of October 1985.

Excavation of seedlings a year later at the end of the first growing season (1986) indicated very little root growth for any of the planting dates (Plate 5, page 25). The principal difference in root growth was between planting sites, with the most root growth occurring on sites with the most shoot growth (ESSF2). Plate 5 shows representative examples of root growth after the first growing season. The most root growth was at the bottom of the plug.

Similar excavations at the end of the fourth growing season (1989) indicated limited root growth (Plate 6, page 26). Unlike in earlier observations, rooting was restricted to the top third of the plug and was adventitious in origin. These results differ from those reported by Burdett *et al.* (1984), who found that root growth greater than 1 m horizontally and 50 cm vertically could be expected from Engelmann spruce after the second growing season. The lack of root growth observed here in adjacent operational plantations remains unexplained.

PLATE 1. Example of severe overwinter damage to a seedling on MS1 in winter 1985–86. In the fall of 1985 there was no apparent damage to the seedling or discoloration of foliage. In spring 1986 (a), this seedling was classed as being severely damaged. Live foliage occurs only below the height of the adjacent slash on the south side of the seedling. By fall 1986 (b), the extent of the damage was very evident: needle loss, interwhorl and whorl buds killed, reduced annual growth, and swollen stem with pitchy lesions. In fall 1989 (c), this early damage was no longer evident, although the growth form of the tree had been distorted.

PLATE 2. Example of a healthy seedling on MS1 after winter 1985–86. In spring 1986 (a), this seedling was undamaged and flushing. This seedling was very sheltered compared to the seedling in Plate 1. By the fall of 1986 (b), the seedling had elongated nearly four times as much as the damaged seedling, although there had been some stem needle loss. In fall 1989 (c), the same seedling did not display the distortion of form exhibited by the damaged seedling.

PLATE 3. Example of repeated overwinter damage to a seedling at MS2. Of course some seedlings never recovered from the initial overwinter damage and were repeatedly damaged in each year. This seedling was excavated in late October 1989 at MS2. Many of the surviving seedlings on this site have a similar appearance. As in Plate 6, the major roots originate adventitiously in the top third of the plug.

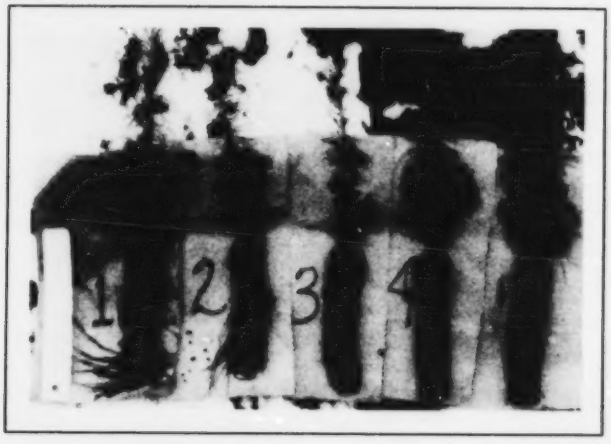


PLATE 4. Root growth during the establishment season for fall planting dates 1985 on MS1. Seedlings arranged according to planting date. Seedlings excavated October 31, 1985 from MS1. Other sites showed comparable root growth (Figure 13). Numbers on the paper bags indicated the planting number (Table 5). Seedlings from all planting dates lack elongated roots in the top two-thirds of the plug. The two earliest plantings display poor plug cohesion. Roots have intentionally been spread to the left to illustrate the amount of root growth.

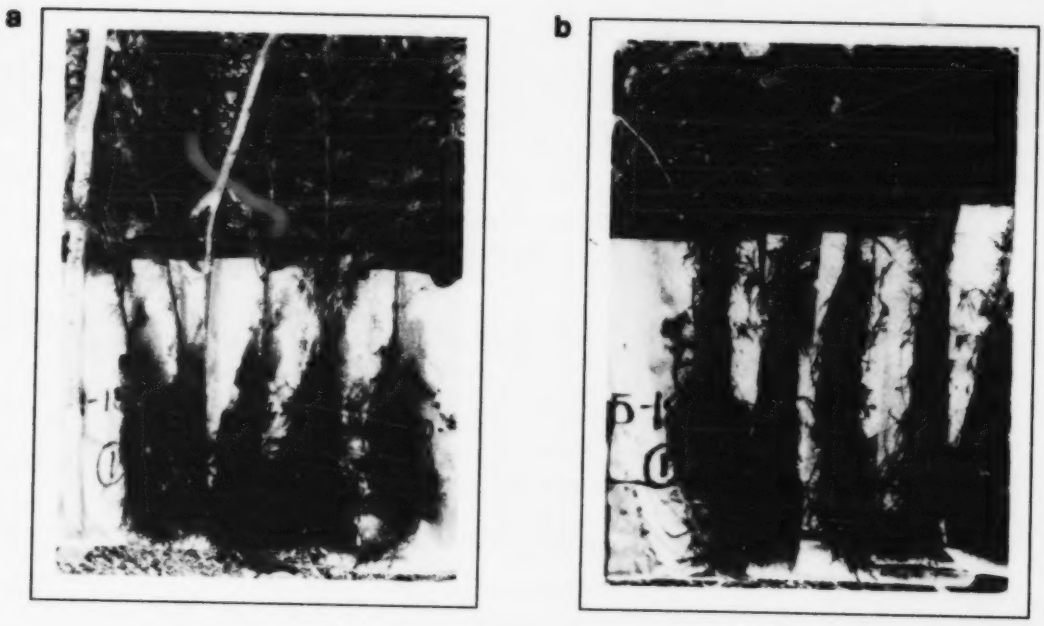


PLATE 5. Root growth after the first growing year (1986) on MS1 and MS2. Seedlings excavated October 31, 1986. Seedlings excavated from MS1 (a) and MS2 (b). Seedlings from MS2 have necrotic and chlorotic foliage and bud damage, and lack the root growth of seedlings from MS1.

4 CONCLUSION

The results indicate that there are few limitations to conducting a successful summer, fall, or spring planting in the ESSF. The situation in the MS is considerably different: earliest plantings are more likely to have superior growth and are less prone to overwinter damage than later planting.

Seedlings that are well established, healthy, and not subjected to physiological stresses before winter will probably tolerate severe climate conditions better than poorly established, unhealthy seedlings. Careful treatment during lifting, transport and planting and attention to climatic and edaphic conditions are the most effective ways of minimizing winter damage on young, high elevation plantations.

5 RECOMMENDATIONS

5.1 Planting Time

Late summer (end of August – early September) and late spring immediately after snowmelt (late May) are optimum planting times. As yet, there is no practical significance to the differences in survival among the planting dates used in this study. Early planting can take advantage of the most favorable climatic and edaphic conditions and may allow for maximum root growth, provided seedlings have hardened-off. Better on-site root growth may result in better physiological adjustment to the site and higher resistance to winter damage.

Compared to spring planting, summer planting may be more cost effective because it eliminates the cost of cold storage of seedlings, the cost of clearing roads of snow to permit access to site, and the possibility of

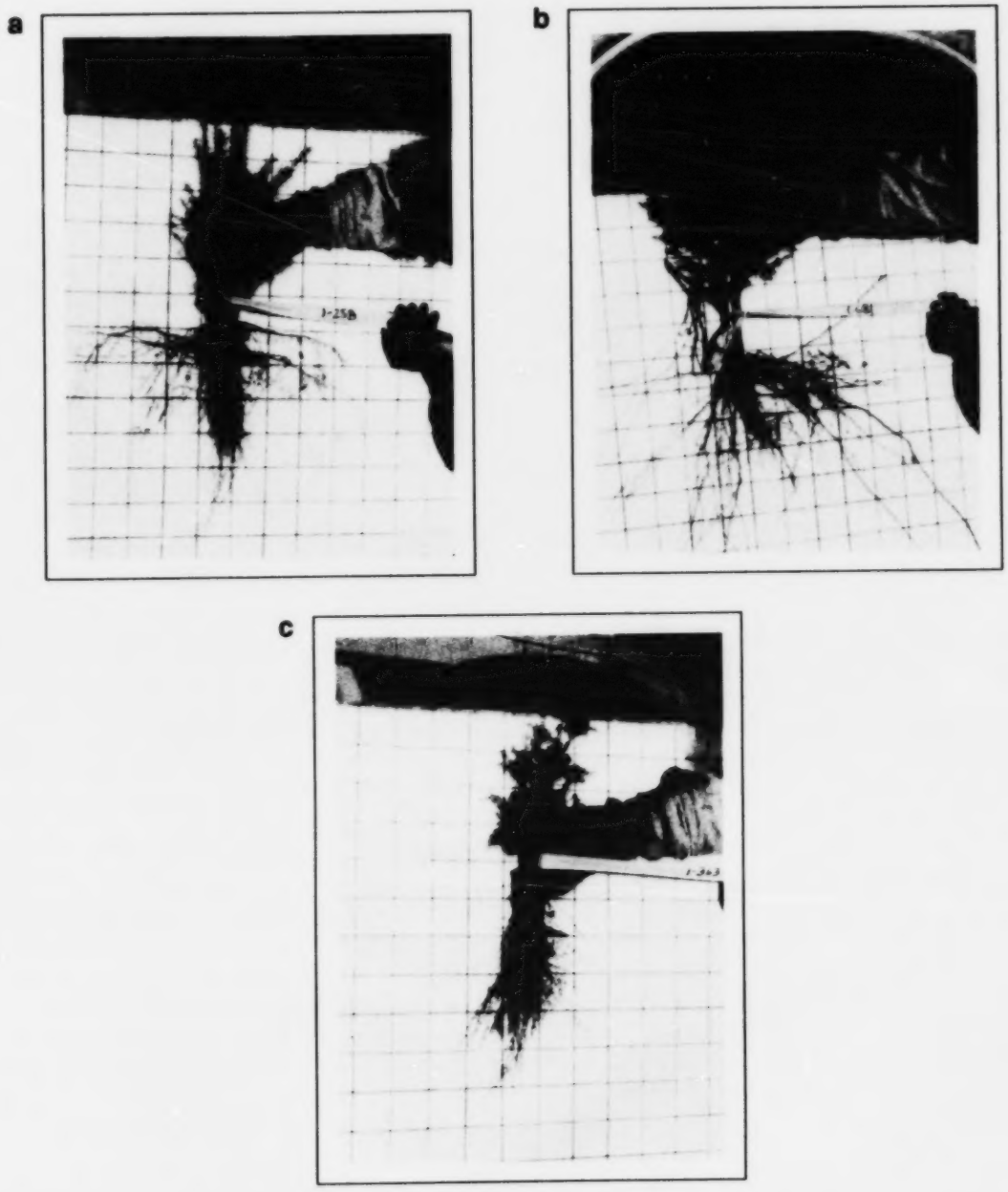


PLATE 6. Root growth after the fourth year (1989) from MS1. Seedlings excavated October 31, 1989. All seedlings excavated from MS1. The seedlings excavated were selected to represent the range of growth observed on this site. Seedlings are from (a) planting #2; (b) spring planting; and (c) planting #3. The plug is still clearly evident in all seedlings and the most profuse rooting has occurred within the top third of the plug from adventitious roots. Adventitious rooting appeared to be stimulated by the organic matter around the root collar.

not gaining access to the site until it is too late to plant. Summer planting also allows greater flexibility in carrying out a planting program. Krumlik's (1984) first approximation of planting guidelines (Table 1) are admittedly conservative, but considering the nature of the microclimate, the stock used, and the logistics of a hot-planting, they remain realistic guidelines. These limits should be regarded as warnings to planting supervisors: if these limits are exceeded, extra care must be used in handling and planting. The further a planting is conducted outside these limits, the less feasible it becomes to achieve acceptable results. In the study area, planting can be initiated as soon as the stock is available, provided site conditions are suitable (which is usually the case).

5.2 Site Preparation and Microsite Selection

Silvicultural systems that increase the snowpack depth and duration may help minimize winter damage, but they could also cause snowpress.

The use of slash or stumps to shelter seedlings may improve microclimate enough to prevent desiccation and frost damage. Roe *et al.* (1970) proposed criteria for the size and distribution of coarse woody debris in order to provide shelter for direct seeding and planted seedlings. Use of sheltering materials that are too small or placement of sheltering material such that it can crush the seedling should be avoided. Constructing shade cards of slash is an expensive treatment. It is more cost effective to allow planters to adjust their spacing to use slash and stumps as found. This requires adjustments in planting tolerance and planting density.

Smaller cutblocks, partial cutting systems, and sheltering treatments by microsite selection may improve snow cover of seedlings and help to minimize winter damage to them. Deeper snow cover will improve soil moisture. Alexander (1986) reviewed a wide variety of silviculture systems designed to reduce climate severity at high elevations. Stathers (1989) presented site factors to be considered to reduce frost damage during the growing season.

The effect of slashburning as part of a silvicultural system should be taken into account if snowpack duration is important. A blackened surface will heat up and melt snow sooner than a roughened, lighter colored surface. Slashburning may therefore promote winter damage.

Vegetation may also serve as a shelter. Adjacent operational plantations in the MS indicate that the best spruce growth is associated with the presence of sheltering shrubs.

6 REFERENCES

Alexander, R.R. 1986. Silvicultural systems and cutting methods for old-growth spruce-fir forests in the central and south Rocky Mountains. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-126.

Alexander, R.R. and W.D. Shepperd. 1984. Silvical characteristics of Engelmann spruce. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-114.

Bergerud, W.A. 1987. Dose-response models for stand thinning with "Ezjet" herbicide injection system. B.C. Min. For., Victoria, B.C. Res. Note 102.

Binder, W.D., P. Fielder, R.K. Scagel, and G. Krumlik. 1990. Temperature and time-related variation of root growth capacity in some conifer tree species. Can. J. For. Res. 20:1192–1199.

Burdett, A.N. 1987. Understanding root growth capacity: theoretical considerations in assessing planting stock quality by means of root growth capacity tests. Can. J. For. Res. 17:768–775.

Burdett, A.N., L.J. Herring, and C.F. Thompson. 1984. Early growth of planted spruce. Can. J. For. Res. 14:644–651.

Burr, K.E., R.W. Tinus, S.J. Wallner, and R.M. Kiney. 1987. Comparison of time and method of mist chamber measurement of root growth potential. *In* Meeting the Challenge of the Nineties: Proc. Intermount. For. Nursery Assoc. T.E. Landis (editor). U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-151, pp. 77–86.

Campbell, D.L., J. Evans, and G.B. Hartman. 1988. Evaluation of seedling protection materials in western Oregon. U.S. Dep. Agric.-BLM Tech. Rep. T/NOR-5.

Cleary, B.D., R.D. Greaves, and R.K. Hermann (editors). 1978. Regenerating Orgeon's forests. Oreg. State Univ. Ext. Serv., Corvallis, Oreg.

Cordell, C.E., R.L. Anderson, W.H. Hoffard, T.D. Landis, R.S. Smith, and H.V. Toko. 1989. Forest nursery pests. U.S. Dep. Agric. For. Serv. Agric. Handb. 680.

Klinka, K. and M.C. Feller. 1984. Principles used in selecting tree species for regeneration of forest sites in southwestern British Columbia. For. Chron. 60:77–85.

Krumlik, G.J. 1984. Fall-planting in the Vancouver Forest Region. B.C. Min. For., Victoria, B.C. Research Rep.-84002-HQ.

Krumlik, G.J. and W.A. Bergerud. 1984. Survival and growth of four Douglas-fir stocktypes 21 years after planting. B.C. Min. For., Victoria, B.C. Res. Note 96.

Lloyd, D., K. Angove, G. Hope, and C. Thompson. 1990. A guide to site identification and interpretation for the Kamloops Forest Region. B.C. Min. For., Victoria, B.C. Land Manage. Handb. 23.

Lundmark, T. and J-E. Hüllgren. 1987. Effects of frost on shaded and exposed spruce and pine seedlings planted in the field. Can. J. For. Res. 17:1197–1201.

Mullin, R.E. 1974. Some planting effects still significant after 20 years. For. Chron. 50:191–193.

_____. 1980. Comparison of seedling and transplant performance following 15 years growth. For. Chron. 56:231–232.

Orlander, G., P. Gemmel, and J. Hunt. 1990. Site preparation: a Swedish review. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 105.

Pendl, F., B. D'Anjou, R.K. Scagel, and R.C. Evans. [1990]. Plantation performance related to the Canadian Fire Weather Index System: 10-year consequences of a time of planting study in the Coast Interior Transition. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 161.

Pollack, J.C. and P. LePage. 1986. An all-season container and bareroot planting trial of lodgepole pine and white spruce: 14-year results. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 4.

Rikala, R. and T. Repo. 1987. Frost resistance and frost damage in *Pinus sylvestris* seedlings during shoot elongation. Scand. J. For. Res. 2:433–440.

Roe, A.L., R.R. Alexander, and M.D. Andrews. 1970. Engelmann spruce regeneration practises in the Rocky Mountains. U.S. Dep. Agric. For. Serv. Prod. Res. Rep. 115.

Ronco, F. 1970a. Chlorosis of planted Engelmann spruce seedlings unrelated to nitrogen content. Can. J. Bot. 48:851–853.

_____. 1970b. Influence of high light intensity on survival of planted Engelmann spruce. For. Sci. 16:331–339.

_____. 1972. Planting Engelmann spruce. U.S. Dep. Agric. For. Serv. Res. Pap. RM-89.

Scagel, R.K., R.E. Green, R.C. Evans, and H. von Hahn. 1989. Exploratory high elevation reforestation trials in the Vancouver Forest Region. 10-year species performance of planted stock. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 98.

Schaap, W. and D. DeYoe. 1986. Seedling protectors for preventing deer browse. Oreg. State Univ., For. Res. Lab., Corvallis, Oreg. Res. Bull. 54.

Seidel, K.W. 1986. Tolerance of seedlings of ponderosa pine, Douglas-fir, grand fir, and Engelmann spruce for high temperatures. N.W. Sci. 60:1–7.

Sloan, J.P. 1989. Fall-lifted Douglas-fir outperforming spring-lifted stock 13 years after planting. Tree Planters Notes 40(3):20–24.

Smith, W.K., E.H. Delucia, and A.K. Knapp. 1987. Environmental limitations to photosynthesis in subalpine plants of the Central Rocky Mountains, USA. *In* Management of subalpine forests: building on 50 years of research. C.A. Troendle, M.R. Kaufmann, R.H. Hamre, and R.P. Winokur (editors). U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. RM-149, pp. 199–206.

Spittlehouse, D.L. 1989. Using data loggers in the field. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 86.

Spittlehouse, D.L. and R.J. Stathers. 1989. Seedling microclimate. B.C. Min. For., Victoria, B.C. Land Manage. Rep. 65.

Spittlehouse, D.L. and S.W. Childs. [1990]. Evaluating the seedling moisture environment after site preparation. *In* Proc. 7th N. Am. For. Soils Conf. Sustained productivity of forest land. In press.

Stathers, R.J. 1989. Summer frost in young forest plantations. B.C. Min. For./For. Can., Victoria, B.C. FRDA Rep. 73.

Stein, W.L. 1978. Reforestation evaluation. *In* Regenerating Oregon's forests. B.D. Cleary, R.D. Greaves, and R.K. Hermann (editors). Oreg. State Univ., Ext. Serv., Corvallis, Oreg., pp. 206–221.

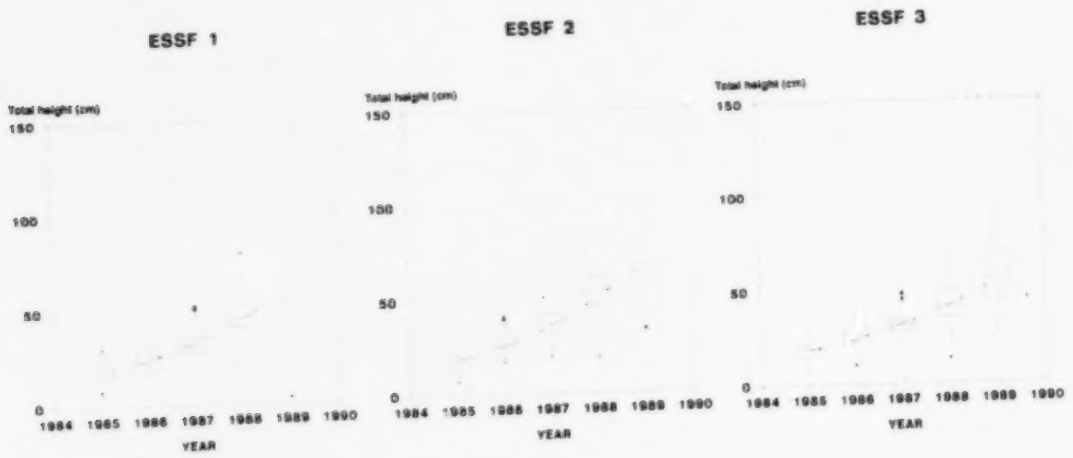
Thompson, C.F. 1974. Tenth year remeasurements of planting trials with ponderosa pine. B.C. Min. For., Victoria, B.C. Res. Note 65.

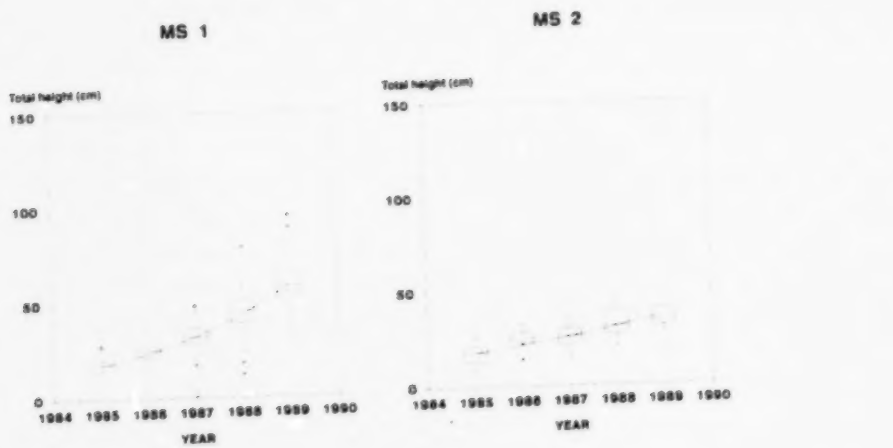
Titus, S.J. 1987. A graphic approach to summarizing forestry data. For. Chron. 63:347–350.

Vyse, A. 1981. Growth of young spruce plantations in the interior of British Columbia. For. Chron. 57:174–180.

APPENDIX 1. Growth curves for seedlings on five experimental sites

Growth curves for each of the five sites are shown below. These curves pool all planting dates. Comparing the growth curves allows users to assess operational plantation performance. Plantation performance assessment should also include seedling excavation to see how the root systems are developing.





APPENDIX 2. Cost analysis

The cost analysis uses parameters that Schaap and DeYoe (1986) and Campbell *et al.* (1988) used to summarize the results of their research on seedling protection from deer browse. The cost analysis is not definitive because it is based on average survival and growth of planting dates within sites. The assumptions of the cost analysis are:

1. Administrative costs are independent of planting date.
2. Administrative overhead covers all tasks through planting.
3. Only one planting is considered. Replant or fill-planting will be more expensive.
4. Harvesting system is clearcut and site preparation is by slashburning. Other site preparation techniques may add more to the cost.
5. Constant planting tolerance is used and is independent of planting date.
6. Mortality is based on experimental research trials. Add 15% mortality for operational plantations.
7. Stock cost is fair market value under progress payment system and includes packaging costs. This cost is specific for Se 2+0 PSB 313b. Early sown Se 2+0 PSB or 1+0 scheduled for summer delivery will add substantially to the seedling cost estimate. Mortality and performance may not be accurate for alternative stocktypes.
8. No provision is made for additional treatments, such as brushing and weeding.
9. Transportation costs, estimated on flat mileage basis, do not consider speciality transport to remote sites.
10. Speciality on-site storage costs are not included.
11. Road repair and snow clearing costs associated with high elevation sites are not included.
12. Costs are not interest bearing.
13. Allowance is not made for overwinter damage except as reflected in mortality, height growth, and diameter growth.

Table A2.1 reports the information required to perform the cost analysis. The following equations and units are used:

1. Planting density (DEN) = target density x (1 - [Mortality x .01]) [seedling/ha]
2. Storage cost (STOR) = (roundup [DEN/packaging unit]) x storage cost [$/ha]
3. Cost to plant (PLANT) = (DEN x [Seedling price + planting price]) + site prep + STOR + transport) + administrative overhead [$/ha]
4. Cost of surviving target seedling (ST) = PLANT/target density [$/seedling]
5. Height cost of surviving target seedling (HST) = ST/height growth [$/cm]
6. Diameter cost of surviving target seedling (DST) = ST/diameter growth [$/mm]

The cost analysis illustrates the magnitude of difference between ESSF and MS sites. Mortality is the major driving variable in the analysis. Planting densities in the MS average 25% greater than the ESSF (Figure A2.1). There is no difference in planting density for different planting times in the ESSF. The cost of planting and establishing Engelmann spruce is much higher, and more strongly related to planting time, in the MS than the ESSF (Figures A2.2–A2.5). There is very little cost difference between planting times in the ESSF. Planting in early August in the MS is not reliable. The optimal planting time in the MS is the end of August and early September, achieving the lowest cost of a surviving seedling and cost of height and diameter growth. This cost analysis does not indicate whether these initial cost-effective strategies will remain cost-effective at rotation.

TABLE A2.1 Cost analysis components and worked example

Example uses values of survival and performance for ESSF2.						
BGCZ:	ESSFmw					
MOIST/NUTR:	3/4					
ECOSYSTEM ASSOC:	ESSF2					
SPECIES, SEEDLOT:	Se 8303					
STOCKTYPE:	PSB 313 2+0					
ASSESSMENT AT:	4 years					
PLANTING DATE:	Aug 13	Aug 28	Sep 10	Sep 23	Oct 8	May 24
Required seedling data						
Mortality (%)	0	0	4	5	0	2
Initial height (cm)	19.4	19.4	19.4	19.4	19.4	19.4
Initial diameter (mm)	4.3	4.3	4.3	4.3	4.3	4.3
Total growth (cm)	70.6	66.5	66.4	67.5	61.3	75.7
Total diameter (mm)	14.4	12.3	13.4	13.4	12.5	14.9
Required site information						
Target stocking (stems/ha)	1200	1200	1200	1200	1200	1200
Required materials and cost information						
Site preparation ($/ha)	300	300	300	300	300	300
Seedling price ($/seedling)	.157	.157	.157	.157	.157	.157
Planting price ($/seedling)	.350	.350	.350	.350	.350	.350
Packaging unit (seedlings/box)	350	350	350	350	350	350
Boxes needed (# boxes/ha)	3	3	4	4	3	3
Storage cost ($/box)	.00	.00	.00	.00	.00	3.50
Transport cost ($/box)	1.00	1.00	1.00	1.00	1.00	1.00
Admin. overhead (%)	11	11	11	11	11	11
Calculated planting density and spacing						
Planting density (stems/ha)	1200	1200	1250	1263	1200	1224
Calculated costs						
Cost to plant ($/ha)	912.40	912.40	938.78	945.46	912.40	935.34
Cost to plant ($/seedling)	.76	.76	.75	.75	.76	.76
Surviving seedling ($/TS)	.76	.76	.78	.79	.76	.78
Height cost ($/cm)	.015	.016	.017	.016	.018	.014
Diameter cost ($/mm)	.075	.095	.086	.087	.093	.074

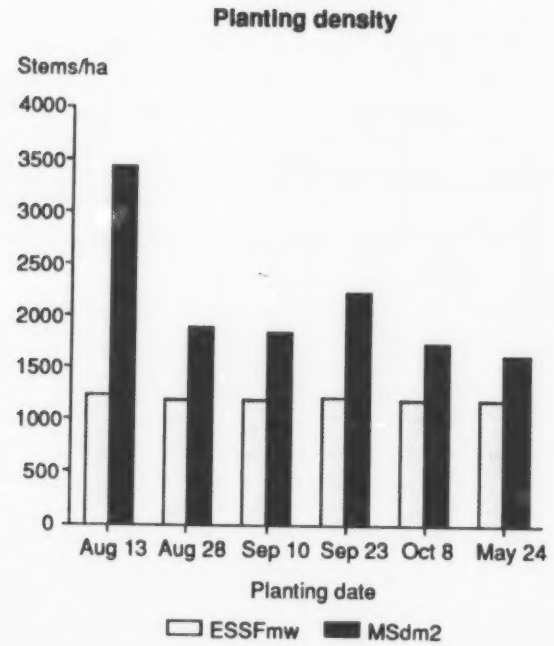


FIGURE A2.1. Planting density necessary to achieve target stocking 5 years after planting. Planting densities averaged separately for sites in the ESSF and MS. Target stocking based on Lloyd *et al.* (1990).

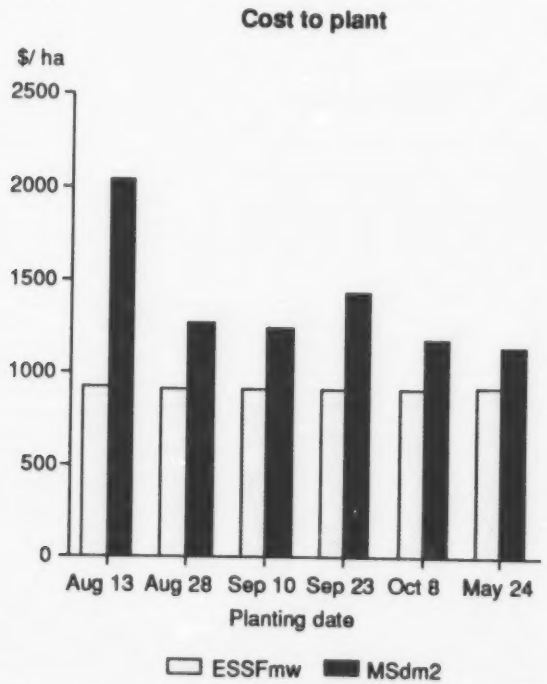


FIGURE A2.2. Cost to plant a hectare to achieve target stocking 5 years after planting. Cost to plant averaged separately for sites in the ESSF and MS.

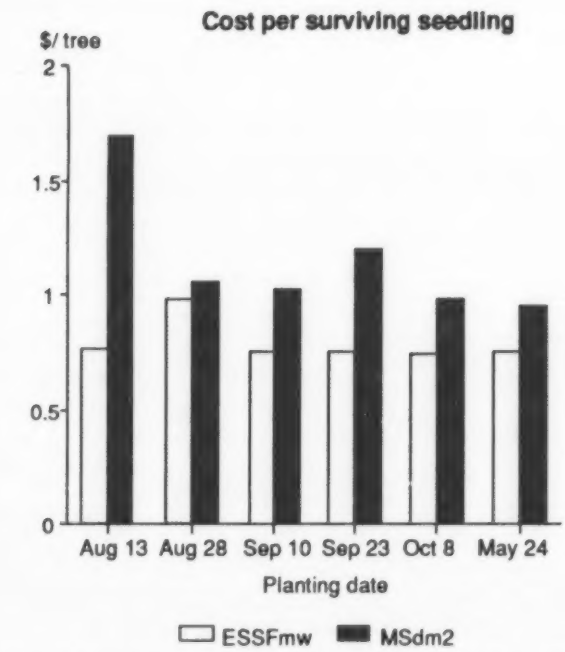


FIGURE A2.3. Cost of surviving target seedling 5 years after planting. Cost of surviving target seedling averaged separately for sites in the ESSF and MS.

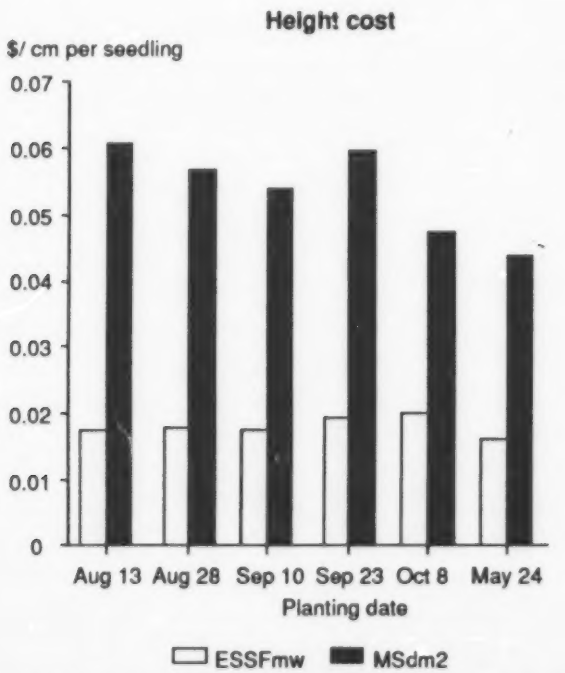


FIGURE A2.4. Height growth cost 5 years after planting. Height growth cost 5 years after planting averaged separately for sites in the ESSF and MS.

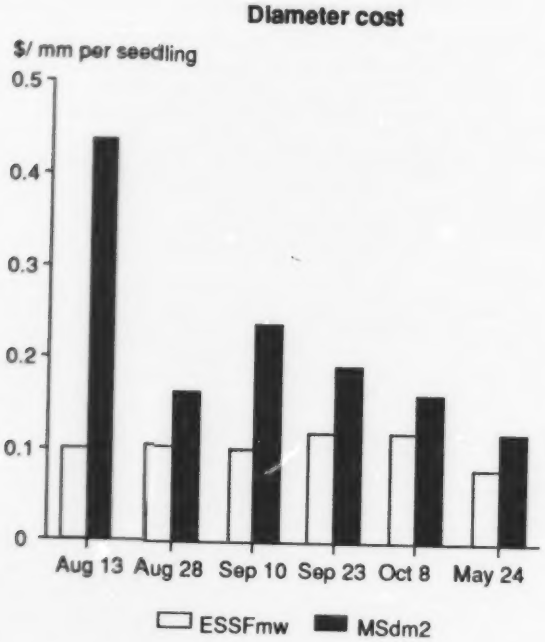


FIGURE A2.5. Diameter growth cost 5 years after planting. Diameter growth costs 5 years after planting averaged separately for sites in the ESSF and MS.